Studies of the Tsushima Current

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LONG-TERM GOALS

To build an understanding of nature of poleward flowing warm water pathways along eastern boundaries of the ocean.

OBJECTIVES

To understand the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current and its relationship to the upstream condition, the Japan Sea warm core eddy field and subpolar front.

APPROACH

To achieve the objectives, we have adopted a two-pronged approach employing both data analysis and modeling.

A. Data Analysis: Using high quality *in situ* hydrographic data and TOPEX Poseidon altimetric data, define the mean, seasonal and interannual variability of Tsushima Current shear and transport in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies.

B. Modeling: Through a two-layer model, the dynamics of the Tsushima Current as a buoyancy-driven flow, and its interaction with the coastal boundary are examined.

WORK COMPLETED

A. Data Analysis: The research began in 1999, with attention directed towards development of the data analysis methods. We began with a high quality, near monthly data set of CTD stations obtained by the Japan Meteorological Agency (JMA) across the Tsushima Current for the years 1995 to 1997. These data nicely define the sea level slope and associated geostrophic flow of the Tsushima current from the Tsushima Strait to the Tsugaru Strait. Sea surface slope relationship to the depth of the 6°C isotherm is determined to enable more quantitative use of the substantial XBT and AXBT data sets. The annual mean form of the transport is found and anomalies from that mean are determined. The mean annual cycle defines the normal mean and seasonal variability of the transport; the anomaly reveals deviations from the mean annual cycle. The nature of the Tsushima Current is related to the eddy field as revealed by the TOPEX POSEIDON data. The JMA data is projected onto TOPEX POSEIDON track lines to aid in enhancement analysis of the 10 day repeat altimetric data: estimation of absolute sea surface slope; determining subsurface thermohaline field associated with sea level anomalies. The TOPEX POSEIDON data is used to develop the seasonal and interannual anomalies of sea surface slope from the TOPEX POSEIDON 5 year mean.

Claudia Giulivi of Lamont-Doherty Earth Observatory participated on the on the Tsushima Current cruise of the research vessel *Hakuho-maru* within the Japan Sea, October 12-25, 1999. The cruise was conducted by the Ocean Research Institute (ORI) in Tokyo. An impressive array of CTD and LADCP stations were collected. Station map shown on: http://dpo.ori.u-tokyo.ac.jp/research/KH9904/map.gif.

B. Modeling: We have pursued two subjects concerning the Tsushima Current dynamics: the branching of the current, and its spawning of eddies when interacting with the boundary. The branching study has resulted in a manuscript titled "A model of a buoyant through-flow with application to the branching of the Tsushima Current." It has completed the review process at the Journal of Physical Oceanography, and is presently in press. Because of the robustness of the branching mechanism, we are collaborating with J. Whitehead at WHOI to see if he can reproduce the branching feature from laboratory experiment. We are also collaborating with Martin Visbeck at Lamont-Doherty to simulate the branching feature using the Lamont Ocean Model. A preliminary run has indeed reproduced the predicted branching, thus corroborating the model. We plan to write a sequel to the above paper, detailing numerical and laboratory studies of the branching phenomenon.

For the second topic, we have proposed a new mechanism for eddy generation via stagnation of the coastal current. We have completed the formulation of the problem and obtained analytical solution. We are in the process of evaluating the analytical solution through numerical simulation. We plan to begin writing the paper before the end of the year.

RESULTS

A Data Analysis: In this the first year of our research we are mainly concentrating on development of the analysis methods. In year 2 we will interpret the results in terms of the project's objectives.

The 1995 to 1997 JMA CTD stations and TOPEX POSEIDON altimetric 10 day repeat tracks (Fig. 1) define the mean annual curve of Tsushima current transport, seasonal and interannual anomalies, and the relationship of the Tsushima Current to warm core eddies.

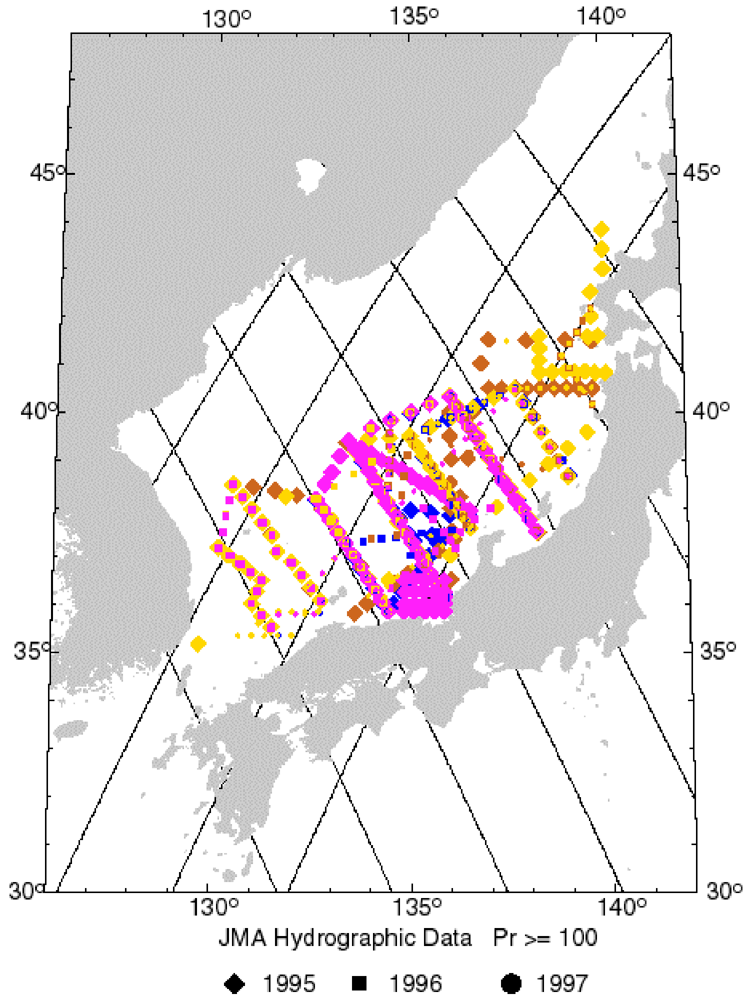

Figure 1. 1995-1997 CTD Stations and corresponding TOPEX/POSEIDON tracks.

In Fig 2 the baroclinic height of sea surface relative to 200 db (dy meters) based on CTD data 'gridded' to a subsampled array of TOPEX POSEIDON data points, is plotted along TOPEX POSEIDON track 10 (the NW/SE track passing just south of the Noto Peninsula, near 37°-38°N at the Japanese coast), along with the depth of the 6°C isotherm (meters) and TOPEX POSEIDON 10 day SSH anomaly (cm) from a 5 year mean along track 10. Each line represents lat/long points along track 10, at roughly 30 km intervals. The values with the highest sea level fall along the Japan coast, the lower values are at the seaward terminus of the CTD data, just to the cold side of the subpolar front, so the full warm water regime of the Japan Sea is represented. Much of the heaving of sea level is due to locally imposed steric changes, but some changes in sea surface slope are apparent. The sea level difference between the coastal region and the subpolar front region is largest (greatest Tsushima transport) by roughly 50% in the Fall of the year. Often the greatest sea slope is found at the subpolar front. The TOPEX POSEIDON data shows similar seasonal changes in sea surface slope. In the Fall season the variability of SSH at TOPEX POSEIDON points within the warm regime is greater than during the Spring season, suggesting more energetic warm core eddies at times of greater Tsushima Current transport. Sea surface slope relationship to the depth of the 6°C isotherm seems rather scattered, but when grouped by season there is hope that a relationship can be found that will help in analysis of the Japan Sea XBT and AXBT data sets.

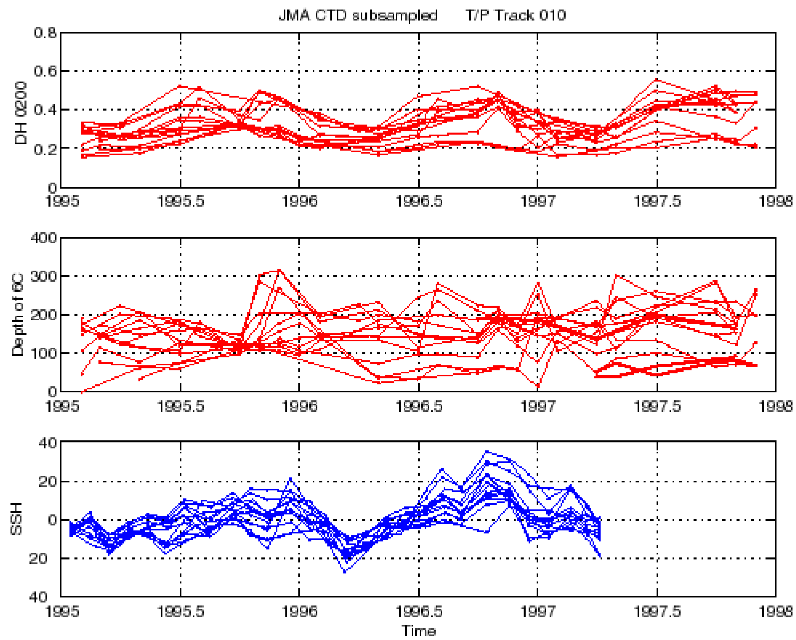

Figure 2. Dynamic height, Depth of the 6° isotherm, and Sea Surface Height along TOPEX/POSEIDON track 10.

B. Modeling: For the branching study, we have proposed a robust mechanism for the branching of a buoyant coastal current debouched from a strait (Fig. 3). It invokes only frictional torque acting on the sill flow, and stretching of the layer as it exits the strait. When applied to the Tsushima Current, it is found that the required conditions for branching are amply satisfied, and its robustness suggests wide applications, including that of river outflow. The model also resolves the outstanding question regarding transport of the Tsushima Current. It is suggested that this transport, including its seasonal variation, can be largely accounted for by the hydraulic control by the strait. Since the transport is found to be scaled by the square of the sill depth, even a small perturbation of the upstream thermocline depth may lead to amplified signal in the transport. This suggests the prospect of detecting small climate signal, such as El Nino, in the variability of the Tsushima Current. The model results thus may help interpret above analysis of the TOPEX/POSEIDON data.

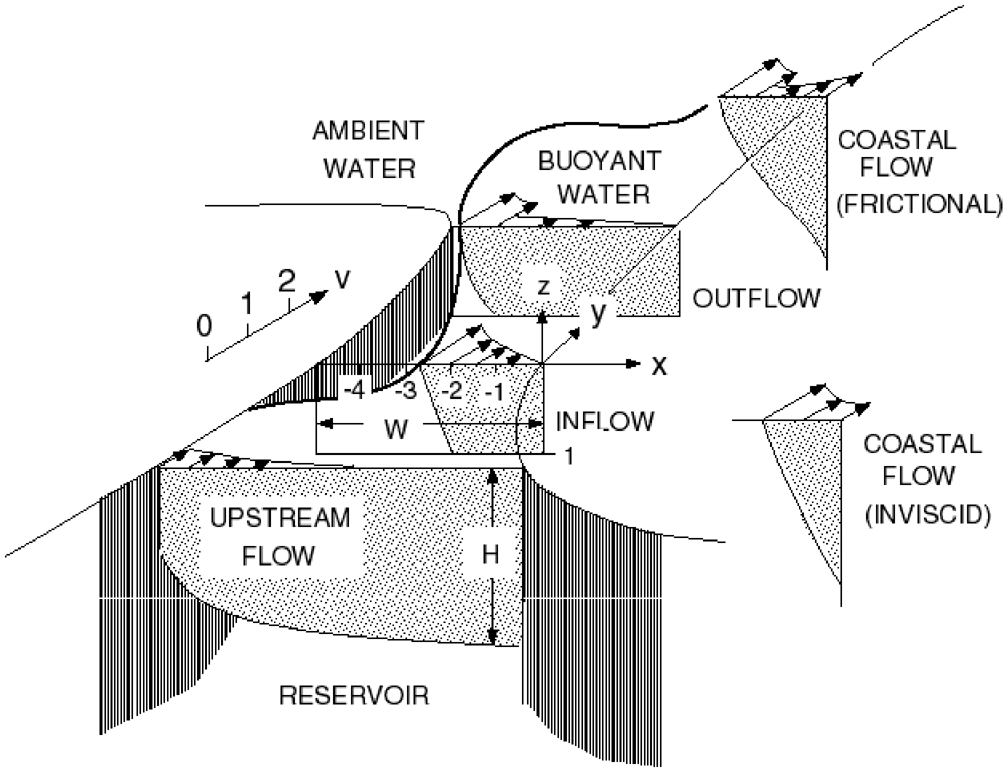

Figure 3. Analytical solution for the buoyant flow through a sea strait connecting two ocean basins. The variables have all been non-dimensionalized, and are representative of the Tsushima Current. The transport is determined by hydraulic control and has a value of about 3 sv. This transport is supplied from the left rim of the upstream basin. The through-flow near the strait entrance has outcropped, but friction has dissipated the anchored flow, causing the buoyant layer to expand to the left wall near the exit of the strait. The stretching of the layer as it exits the strait causes the coastal flow to exhibit two velocity maxima --- along the outcrop and the coastal boundary.

For the second study, we have proposed a new mechanism for eddy generation which invokes stagnation of the wall velocity. This stagnation can be facilitated by changes of many external conditions, including decrease of bottom slope, a boundary curving into the current, the planetary beta effect, and the cooling by air-sea fluxes. The mechanism thus may provide explanation to many regional generation of eddies. It is fundamentally different from the classical problem of boundary layer separation accompanied by swirls, since eddies are generated when boundary curves into rather than away from the current. From the model solution, one may determine properties of the eddies and their dependence of the upstream conditions, which can be assessed by our data analysis effort.

TRANSITIONS

The Tsushima Current research will be linked to the rest of the JES program results. The annual JES workshops (see: http://sam.ucsd.edu/onr_jes) provide opportunity to develop such transitions.

RELATED PROJECTS

None

PUBLICATIONS

Ou, H-W. 1999. A model of a buoyant through-flow with application to branching of the Tsushima Current. J. Phys. Oceanogr. (in press)